SPECIFICATION

TITLE

"MAGNETIC RESONANCE DEVICE WITH A BASIC FIELD MAGNET AND AT LEAST ONE GRADIENT COIL"

BACKGROUND

The invention concerns a magnetic resonance device.

Magnetic resonance technology is a known technology to, among other things, acquire images of the inside of a body of an examination subject. In a magnetic resonance device, rapidly switched gradient fields that are generated by a gradient coil system are thereby superimposed on a static homogenous basic magnetic field that is generated by a basic field magnet. The magnetic resonance device also comprises a radio-frequency system that radiates radio-frequency signals into the examination subject to excite magnetic resonance signals, and acquires the excited magnetic resonance signals on the basis of which magnetic resonance images are created.

To generate the gradient field, corresponding currents are adjusted in the gradient coil. The amplitudes of the required currents thereby amount to more than 100A. The current rise and fall rates amount to more than 100 kA/s. An existing basic magnetic field affects these temporally changing currents in the gradient coil on the order of 1T Lorentz forces, that lead to oscillations of the gradient coil system. These oscillations are reproduced over various propagation paths at the surface of the magnetic resonance device. The mechanical oscillations are thereby transduced into sound vibrations that subsequently lead to an undesired noise. Furthermore, the

Lorentz forces can also lead to an undesired rigid-body motion of the gradient coil system with regard to the rest of the magnetic resonance device.

A reduction in principle of oscillations of the gradient coil system via an active technique is specified in DE 44 32 747 A1. For this, a device comprising in particular electrostrictive elements is arranged in or on the gradient coil system. With this device, forces can be generated that counteract the oscillations of the gradient coil system such that a deformation of the gradient coil system is substantially prevented. However, this solution is cost-intensive, in particular due to the high expenditure in connection with the electrostrictive elements, their arrangement and their regulation.

A method to operate a magnetic resonance device is specified in DE 199 03 627 A1 in which forbidden frequency bands are defined around the resolution frequencies of a gradient coil system, and the gradient coil currents are controlled in the framework of pulse sequences such that they exhibit no spectral components within these forbidden frequency bands, such that an excitation of noise peaks is prevented. However, this solution also represents no general loophole, since it influences only the resolution frequency ranges.

Finally, a gradient coil system is known from DE 198 29 298 A1 with which only a part of the body of a patient, for example his head, can be imaged. The gradient coil system thereby comprises an asymmetrical gradient coil that is assembled with a turning moment-compensating conductor design.

SUMMARY

It is an object to achieve an improved magnetic resonance device in which, among other things, a lower noise emission is achieved.

In a magnetic resonance device, a basic field magnet generates a basic magnetic field that exhibits, within an imaging volume of the magnetic resonance device, the main component oriented in a predeterminable direction. At least one gradient coil is arranged in a region of a gradient magnetic field in which the basic magnetic field exhibits at least one secondary component perpendicular to the main component. Conductors of the gradient coil are arranged such that, given flow of an electrical current in the conductors, a turning moment operating via the main component and effecting a part of the gradient coil is at least partially compensated by a turning moment acting via the secondary component.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a longitudinal section through a superconducting coil and a gradient coil of a magnetic resonance device; and

Figures 2, 3 and 4 show azimuthal and axial currents in a basic magnetic field with an axial main component and a radial secondary component.

DESCRIPTION OF THE PREFERRED EMBODIMENT

For the purpose of promoting an understanding of the principles of the invention, reference will now be made to a preferred embodiment illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is

thereby intended, such alterations and further modifications in the illustrated device, and/or method, and such further applications of the principles of the invention as illustrated therein being contemplated as would normally occur now or in the future to one skilled in the art to which the invention relates.

The mechanical oscillation tendency of the gradient coil is directly reduced at the creation point via the compensation of bending moments that can be effected, whereby a high noise-reducing effect is achieved and limitations of previous solution approaches are overcome. The preferred embodiment is based on the realization that the basic magnetic field already exhibits a sufficiently large secondary component perpendicular to the main component in the region in which the conductors are typically arranged, and the secondary component can be used in connection with a corresponding conductor arrangement to compensate turning moments. In comparison to a comparable conventional gradient coil, the gradient coil provided thereby exhibits an inductivity increased by only a few percentage points, given otherwise identical properties.

In an advantageous embodiment, the gradient coil is a transversal gradient coil of a gradient coil system for a magnetic resonance device with a substantially cylindrical patient acceptance space. The design of the transversal gradient coil is particularly advantageous since the saddle-shaped coils of the transversal gradient coil through which current flows, in connection with the main component, provided turning moments that strain the gradient coil system to bending, and the rigidity of the gradient coil system with regard to the bending moments is comparably small such that large elastic

deflections, and therewith noise, would be created without the embodiment disclosed. Moreover, the fundamental eigen frequency of the gradient coil system for the most part lies in the range of strong spectral components of the associated gradient coil current. Without the embodiment provided, the excitation of mechanical resonances thereby possible would lead to a repeated substantial noise increase. The forces of a longitudinal gradient coil occurring in connection with the main component substantially radially stress the gradient coil system. Due to the high rigidity of the gradient coil system with regard to such stresses, only comparably slight elastic deformations occur, such that the acoustic sound emission typically remains small. Moreover, all resonance frequencies for the most part lie sufficiently far above the largest part of the power spectrum of the associated gradient coil current. A lengthwise shearing force caused by the secondary component of the basic magnetic field can thereby be easily remedied via a suitable positioning of the conductor for a given basic field magnet.

Figure 1 shows, as an exemplary embodiment, a longitudinal section through a superconducting coil 10 of a basic field magnet and a transversal gradient coil of a magnetic resonance device with a tunnel-like patient acceptance space. For reasons of clarity, the superconducting coil 10 and the transversal gradient coil are shown cut free of the rest of the components of the magnetic resonance device. The remaining components comprise, for example, a helium vessel, cryoshield and a vacuum vessel of the basic field magnet, as well as further gradient coils, shielding coils, shim coils and an epoxy seal [encapsulation] of a gradient coil system, as well as a radio-

frequency antenna system. Four annular windings of the superconducting coil 10 are exemplarily shown. The transversal gradient coil comprises a left and a right coil half with two saddle-shaped, opposing sub-coils 21 and 22 as well as 28 and 29 per coil half. Likewise, for reasons of clarity only one winding is exemplarily shown per sub-coil 21, 22, 28 and 29.

Given a corresponding current flow in the superconducting coil 10, the basic field magnet generates an optimally homogenous static basic magnetic field, at least within an imaging volume 15 in the direction of a cylinder main axis, that is created via a connection of the center points of the annular windings of the superconducting coil 10. The symbol ⦿ designates a current flow exiting from the drawing plane, and the symbol ⊗ designates a current flow entering into the drawing plane. In the region in which the windings of the sub-coils 21, 22, 28 and 29 are arranged, the basic magnetic field is no longer homogenous and also comprises, in addition to a main component B_z in the direction of the cylinder main axis, a radially-directed secondary component B_r.

Due to the main component B_z of the basic magnetic field, in the region of the slice plane of Figure 1 the forces designated with F_{Bz} (that effect a turning moment M_z with regard to a focal point 24 of the right coil half) act on the sub-coils 21 and 22 of the right coil half. For determination of the forces F_{Bz} according to direction, a current flow is thereby accepted in the sub-coils 21 and 22 that is established by the symbols ⦿ and ⊗ explained in the superconducting coil 10. According to the preferred embodiment, the conductors of the sub-coils 21 and 22 are furthermore arranged such that,

due to the radial secondary component B_r of the basic magnetic field, forces F_{Br} (that, with regard to the focal point 24, generate a turning moment M_r that optimally, completely counteracts the turning moment M_z) act in the region of the slice plane on the sub-coils 21 and 22 through which current flows. A turning moment compensation is therewith achieved for the coil halves arranged, for example, in a hollow-cylindrical cast-resin seal. The same correspondingly holds true for the sub-coils 28 and 29.

The preceding specification is correspondingly applicable to an actively-shielded gradient coil that comprises a primary coil and a shielding coil, whereby the further conductors of the shielding coil are to be considered in addition to the conductors of the primary coil as the (as it were) actual gradient coil. The sums of turning moments and forces originating from both the primary coil and the shielding coil are thereby to be considered for the compensation.

The preceding specified conductor arrangement of the gradient coil originates from a fixed predetermined curve of the secondary component B_r due to a previously implemented basic field magnet design. In other embodiments, the naturally basic field magnet and gradient coil can be designed tuned to one another, such that the curve of the secondary component B_r can be controlled to a certain extent via the design of the basic field magnet.

Specified in the following is a procedure to determine the turning moment-compensating conductor arrangement of the gradient coil. For this, it is advisable for the subsequent considerations to separate the transversal

gradient coil in rings whose currents respectively possess purely azimuthal and purely axial components. Since the transversal gradient coils generate a transversal gradient perpendicular to the cylinder main axis, the azimuthal current I_k in each ring is substantially proportional to the cosine of the azimuthal angle φ and the axial currents I_j are substantially proportional to the sine of the azimuthal angle φ. The forces considered in the following are thereby substantially caused by the azimuthal currents I_k. If a ring k possesses the radius r_k and the axial position z_k, the force $F_{z;k}$ caused in the gradient direction by the azimuthal current I_k and the main component $B_z(r_k;z_k)$ of the basic magnetic field is:

$$F_{z;k} = I_k r_k B_z \int_0^{2\pi} \cos^2 \varphi d\varphi = \pi I_k r_k B_z$$

Figure 2 correspondingly illustrates this. This force $F_{z;k}$ causes a turning moment:

$$M_{z;k} = F_{z;k} z_k = \pi I_k r_k z_k B_z$$

The turning moment $M_{r;k}$ around a transverse axis perpendicular to the gradient direction, originating from the radial secondary component $Br(r_k;z_k)$ of the basic magnetic field with regard to the azimuthal currents I_k via the transverse force $F_{r;k}$, is:

$$M_{z;k} = F_{r;k} r_k = I_k r_k^2 B_r \int_0^{2\pi} \cos^2 \varphi d\varphi = \pi I_k r_k^2 B_r$$

Figure 3 correspondingly illustrates this.

The effective total turning moment M_{azi} of the azimuthal currents I_k is thereby:

$$M_{azi} = \pi \sum_k I_k r_k (r_k B_r + \check{z}_k B_z)$$

Given the existence of the radial secondary component B_r of the basic magnetic field, the longitudinal currents I_j likewise generate a transverse force F_j:

$$F_j = -\Delta z B_r \int_0^{2\pi} \sin^2 \varphi d\varphi \sum_{j<k} I_j = -\Delta z B_r \sum_{j<k} I_j$$

Figure 4 correspondingly illustrates this. Δz is thereby the conductor length forming the basis of the longitudinal current I_j. The transverse force F_j evokes an additional turning moment contribution M_j:

$$M_j = F_j z_k = -\pi z_k \Delta z B_r \sum_{j<k} I_j$$

In order to compensate against each other the transverse forces $F_{r;k}$ and F_j of the transversal gradient coil, the following expression is to be

incorporated as an additional boundary condition in the optimization of the current distribution of the gradient coil:

$$\sum_{k}\left(I_k r_k B_z - \Delta z B_r \sum_{j<k} I_j \right) = 0$$

The fundamental bending or flexing vibration mode is excited via the oppositely-directed sum turning moments of both coil halves, meaning via the load of the coil cross section in the plane z = 0. To reduce the bending moment, it is necessary to reduce or to eliminate the total turning moment of each coil half. The aforementioned sum turning moment is thus, for example, to be formed over all k of a coil half. An additional boundary condition is thereby to be introduced given the optimization of the gradient coil:

$$\sum_{k}\left(I_k r_k \left(r_k B_r + z_k B_z\right) - z_k \Delta z B_r \sum_{j<k} I_j \right) = 0$$

The determination of the reference point z = 0 with regard to the turning moments $M_{z;k}$ and $M_{r;k}$ is irrelevant when the transverse forces $F_{r;k}$ and F_j are also compensated. Alternatively, it suggests itself to use the focal point of the corresponding coil half, since the magnetic forces in the frequency range of interest are mainly intercepted via inertial forces, and then cause no sum turning moment.

The conductor arrangement of the gradient coil can be clearly determined based on the preceding specifications. In other embodiments, the

arrangement of the coils can also be determined via other design methods, for example the design method specified in DE 100 11 034 A1, whereby for this conditions specified in the preceding are correspondingly considered.

While a preferred embodiment has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiment has been shown and described and that all changes and modifications that come within the spirit of the invention both now or in the future are desired to be protected.